Fermilab Steering Group Report
(Internal Report)

August 7, 2007

Chapter 1. Fermilab, the Future and the Quantum Universe

Particle physicists are on a 21st-century quest to answer profound questions about the universe.

1. Are there undiscovered principles of nature: new symmetries, new physical laws?
2. How can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Do all the forces become one?
5. Why are there so many kinds of particles?
6. What is dark matter? How can we make it in the laboratory?
7. What are neutrinos telling us?
8. How did the universe come to be?
9. What happened to the antimatter?

Powerful new scientific tools for particle physics and astrophysics now bring the answers to these compelling questions within reach. Along with astrophysical observations, particle accelerators offer different paths to the exploration of the physics of the Quantum Universe. At the energy frontier, the Large Hadron Collider at CERN and the proposed International Linear Collider will take physicists into a new “Terascale” energy region and the discoveries it holds. High-intensity accelerators provide another pathway to discovery by opening the door into the world of neutrinos and precision physics, where physicists expect they will also find answers to Quantum Universe questions.

The energy-frontier machines, the LHC and the proposed ILC, give physicists the possibility of discovering new symmetries and new physical laws; of finding extra dimensions of space; and of finally penetrating the mystery of the origin of mass. Understanding the nature of dark matter will require energy-frontier accelerator programs to produce dark matter and analyze its properties. As the LHC nears completion, the adventure of Terascale science is about to begin. Experiments at the LHC, built in Europe with U.S. participation, will provide a first look at the Terascale. Hundreds of U.S. particle physicists will join collaborators from around the world in the largest scientific experiments ever conducted.

Physicists plan to build on the discoveries at the LHC with experiments at the proposed International Linear Collider. The ILC would allow experimenters to explore the new scientific landscape of the Terascale, revealing the properties of new phenomena and building the foundation for a clear and consistent understanding of this new energy terrain. Beyond this, precision measurements from the ILC could act as a telescope to reveal secrets from the much higher energies of the ultimate unification of forces and of matter.

Neutrino experiments, which have recently succeeded in detecting new physics, offer their own window on unification, the question of whether all the forces and particles of matter become one. Neutrinos also have the unique potential to explain our cosmic beginnings from a process called leptogenesis. As part of Fermilab’s world-class program in neutrino science, the laboratory has embarked on the NOvA experiment. NOvA will provide the first chance at determining the relative masses of neutrinos, a key piece of information for understanding the role of neutrinos in unification. NOvA is also the first step toward experiments using high-intensity neutrino beams to detect the matter-antimatter properties of neutrinos that leptogenesis requires. Neutrino discoveries could link up with LHC or ILC discoveries of phenomena such as supersymmetry or lepton flavor violation, the morphing of one kind of charged lepton to another.

As the U.S. particle-physics community embarks on this global journey of discovery, the P5 subpanel of the High Energy Physics Advisory Panel in 2006 laid out a roadmap for particle-physics research over the next decade in the United States. The P5 roadmap set priorities for U.S. particle physics aimed at maximizing the potential for discovery. Fermilab's research program of

- energy frontier physics starting with the Tevatron, continuing with the Large Hadron Collider, and culminating with the proposed International Linear Collider
- accelerator-based neutrino physics
- particle astrophysics focusing on dark matter and dark energy

is strategically aligned with the P5 roadmap.

The P5 roadmap charts a course for U.S. particle physics at a key moment in the life of the field. While accelerator-based particle physics is exciting and strong internationally, particle physics in the United States is confronting a very challenging period. By the end of the decade, the world-class programs at the Tevatron, the PEPII B-Factory and CESR will be complete. The contributions of U.S. facilities to global particle physics will then come solely from the Main Injector at Fermilab for a neutrino physics program, and from a test-beam program for evaluating new and innovative detector concepts. In the U.S., an era of world-leading accelerator-based science at the energy frontier will come to an end. On the other hand, the conclusion of research at these U.S. accelerator facilities provides the opportunity to redirect resources towards hosting the ILC in the U.S. in order to continue the nation's historical role as a leader in the global science of particle physics.

Throughout Fermilab's history, the heart of the laboratory's scientific research has been the quest to solve the mysteries of the universe using energy-frontier particle accelerators. Because of its unique discovery potential and its significance for the national program, the ILC is Fermilab's highest priority for the future. Fermilab is committed to leadership in the international effort to build the ILC as early as possible and is a strong contributor to the Global Design Effort.

Following the technology choice for the ILC in 2004, the Global Design Effort and the international ILC community produced a Reference Design Report in February 2007 and are currently preparing an Engineering Design Report, required for a decision to build the ILC, that will be complete in 2010.

The "technically driven" timeline for the ILC, based solely on technical readiness to proceed with the project, calls for a decision to go forward with the new collider in 2010 and for an ILC construction start early in the next decade. The P5 Panel assumed such a timeline in developing the roadmap for U.S. particle physics. However, because factors besides technical feasibility may postpone the start of the ILC, it becomes necessary to carefully plan the U.S. particle-physics program both to secure the ILC and to continue to contribute to particle physics discovery during a possibly extended period before the ILC can open up new scientific horizons.

The Fermilab Steering Group has developed a plan that keeps the laboratory and U.S. particle physics on the pathway to discovery, both at the Terascale with the ILC and in the domain of neutrinos and precision physics with a high-intensity accelerator. The plan does this by creating opportunities for a broad program at the intensity frontier for neutrinos and for ultraprecise experiments that are sensitive to physics beyond the Standard Model.

If the ILC start is postponed significantly, a central feature of the proposed Fermilab plan calls for building an intense proton facility, Project X, consisting of a linear accelerator with the currently-planned characteristics of the ILC, Fermilab's existing Recycler Ring, and the Main Injector accelerator. The major component of Project X is the linac. Cryomodules, RF distribution, cryogenics and instrumentation for the linac are the same as those used in the ILC at a scale of about one percent of a full ILC linac.

Project X's intense proton beams would provide a path to discovery in neutrino science and precision physics with charged leptons and quarks. Through world-leading experiments in leptogenesis, neutrino mass hierarchy, matter-antimatter asymmetry and lepton flavor violation, it would give Fermilab users a way to address key questions of the Quantum Universe: How did the universe come to be? Are there undiscovered principles of nature: new symmetries, new physical laws? Do all the particles and forces become one? What happened to the antimatter?

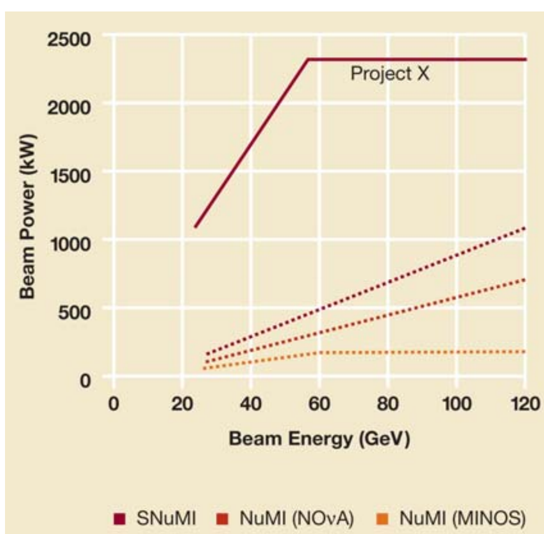

Figure 1. Beam power vs. beam energy for possible proton facilities at Fermilab. SNuMI is an upgrade of NuMI.

Building Project X's ILC-like linac would offer substantial support for ILC development by accelerating the industrialization of ILC components in the U.S. and creating an engineering opportunity for ILC cost reductions. When ILC begins operations, Project X could serve as the injector into a prototype damping ring to cut ILC commissioning time. It offers an early and tangible application for ILC R&D in superconducting technology, attracting participation from accelerator scientists worldwide and driving forward the technology for still higher-energy accelerators of the future, such as a muon collider.

To prepare for a future decision, the Fermilab Steering Group recommends that the laboratory seek immediate R&D support for Project X, in order to produce an overall design of Project X and to spur the R&D and industrialization of ILC linac components needed for Project X. Advice from the High Energy Physics Advisory Panel will guide any future decision to upgrade the Fermilab accelerator complex, taking into account developments affecting the ILC schedule and the continuing evaluation of scientific priorities for U.S. particle physics. Fermilab should also work toward increased resources for longer-term future accelerators such as a muon collider, aiming at higher energies than the ILC would provide.

The goal of the Fermilab plan is scientific discovery in accelerator-based particle physics. In line with the P5 priorities, the plan represents the best strategy to ensure the continuing U.S. capability to address the compelling questions of particle physics using the unique scientific potential of particle accelerators. The plan is flexible, offering options to address the scientific opportunities and challenges facing particle physics in the U.S. today. It maintains the ILC as the central feature of the Fermilab accelerator-based particle-physics plan and advances progress on technologies that will be needed for future frontier accelerators, such as a muon collider. It also provides significant discovery opportunities should the timeline for ILC construction stretch out for any number of reasons: physics discoveries, federal funding decisions, international agreements, site decisions for the ILC and other factors. Fermilab's plan maintains the potential for accelerator-based discovery in the U.S. both at the energy frontier with the ILC and with intense proton beams in the event of a deferred ILC. Crucially, the plan strengthens ties with university scientists and with other laboratories and provides scientific training and education for hundreds of graduate students, the next generation of particle physicists.

For U.S. particle physics, the decade ahead will bring great scientific opportunity and great challenges. Our questions for the universe could not be more profound or more compelling, made more so because the means to address them are at last within reach. How the university and laboratory community comes together with government to meet the challenges and rise to the scientific opportunities is likely to shape the course of particle-physics research in the United States for a long time to come. In this context, Fermilab has a unique responsibility as the nation's primary particle physics user facility. The Fermilab Steering Group has attempted to create a plan for the laboratory that is pragmatic, scientifically exciting and flexible enough to meet the challenges of a still-unfolding future and to provide for Fermilab's users the greatest possible opportunity for scientific discovery.

Chapter 2. Executive Summary: A Plan for Fermilab

The Steering Group has adopted a number of guidelines in forming the plan.

1. The LHC program is our most important near-term project given its broad science agenda and potential for discovery. It is essential to support the physics analysis, computing, and accelerator and detector upgrades.

2. The particle physics community's highest priority for investment toward the future is the ILC, based on our present understanding of its potential for breakthrough science. Fermilab will continue to participate vigorously in the international R&D program for the ILC and to be one of the leaders in the global ILC effort. The laboratory will strive to make the ILC at Fermilab a reality by accomplishing the preparatory work required for the U.S. to bid to host the ILC.

3. There must be an intermediate science program in case the timeline for ILC is stretched out. This program will be an opportunity to do exciting physics that complements discoveries at energy frontier facilities, and to make further progress on ILC technology. The program should provide great discovery potential, support ILC R&D and industrialization as well as R&D on future accelerators beyond the ILC and LHC, and strengthen ties with the university community and with other laboratories. The plan must be robust and flexible.

4. Fermilab will continue a phased program to study dark matter and dark energy through astrophysical observations. The program will allow complementary discoveries to those expected at the accelerator-based particle physics programs. These non-accelerator-based efforts are outside the Steering Group's charge, and not included in the plan.

Based on these planning guidelines, the Steering Group recommends the following plan for the accelerator-based particle physics program at Fermilab.

- Fermilab's highest priority is discovering the physics of the Terascale by participating in LHC, being one of the leaders in the global ILC effort, and striving to make the ILC at Fermilab a reality.
- Fermilab will continue its neutrino program with NOvA as a flagship experiment through the middle of the next decade.

- If ILC remains near the GDE-proposed timeline, Fermilab will focus on the above programs.
- If ILC departs from the GDE-proposed timeline, Fermilab should pursue additional neutrino science and precision physics opportunities by upgrading the proton accelerator complex.
  - If ILC start must wait for a couple of years, the laboratory should undertake the SNuMI[1] project.

[1] SNuMI is an upgrade of NuMI.

  - If ILC postponement would accommodate an interim major project, the laboratory should undertake Project X[2] for its science capability and ILC alignment.
- If ILC is constructed offshore, Fermilab should pursue additional neutrino science and precision physics opportunities by upgrading current proton facilities while supporting the ILC as the highest priority.
  - The laboratory should undertake SNuMI at a minimum.
  - Or the laboratory should undertake Project X if resources are available and ILC timing permits.

- In all scenarios,
  - R&D support for Project X should be started now, emphasizing
    - expediting R&D and industrialization of ILC cavities and cryomodules
    - overall design of Project X
  - R&D for future accelerator options concentrating on neutrino factory and muon collider should be increased.[3]
  - The laboratory should support detector R&D and test beam efforts for effective use of future facilities.

Chapter 3. Physics Opportunities at the Intensity Frontier

The Standard Model of Particle Physics succeeds brilliantly at explaining the nature of the physical universe, but it leaves many open questions. Despite the development of myriad intriguing theories to address these questions, ultimately only experiment can light the way to discovery. In our own time, energy-frontier experiments can search directly for new physics beyond the Standard Model. Remarkable recent discovery and developments in neutrino science have opened another window on further discoveries. Physicists can also search for new physics in the small perturbations they induce in other processes. Chapter 1 briefly discussed physics opportunities with energy-frontier accelerators, the LHC and the ILC; other publications have described at length the compelling physics of the Terascale. This chapter focuses on other accelerator-based opportunities where experiments in symmetry-violating processes and rare decays can provide windows into new mass scales of many thousands of TeV/c^2, and neutrino experiments may tell us about physics at even higher energies of unification.

3.1 Neutrino Science

An upgrade to the Fermilab proton complex could greatly enhance the laboratory's current world-class program of neutrino science by strengthening Fermilab's flagship

---

[2] Project X consists of an 8 GeV ILC-like linear accelerator and reconfigurations of the existing Recycler and Main Injector. The accelerator portion would be similar in size and scope to the Main Injector. Construction would take four to five years with a few hundred FTEs per year. It would be most effectively mounted as an inter-laboratory collaboration centered at Fermilab.

[3] The total annual U.S. R&D budget needed for the neutrino factory and muon collider is estimated to be approximately $20M.

program of long-baseline neutrino oscillation experiments. It would provide the opportunity for a next-generation experiment with potential to discover CP violation in the leptonic sector, and consequently to explore leptogenesis as the source of matter-antimatter asymmetry in the evolution of the universe. It would also provide an opportunity to perform new, smaller-scale experiments using intense neutrino beams generated by 8 GeV and 800 GeV protons that would complement the long-baseline program and provide their own scientific capability.

Long-baseline neutrino oscillations

The Neutrino Scientific Assessment Group, convened by HEPAP and NSAC, and a study group originally commissioned by Fermilab and Brookhaven National Laboratory have recently studied and documented the physics opportunities of long-baseline neutrino experiments. As laid out by NuSAG, the long-baseline program has as its primary goals to complete our understanding of neutrino mixing and oscillations, in particular to determine the ordering and splitting of the neutrino mass states; to measure the mixing angles; and to determine whether there is CP violation in neutrino mixing. The study of CP violation in neutrino oscillations is especially compelling because CP violation in the leptonic sector may explain the very fundamental problem of the matter-antimatter asymmetry of the universe through the process known as leptogenesis. Discovering the ordering of the neutrino mass states will help determine whether neutrino mass is related to the unification of the forces, and whether neutrino oscillations violate CP. Provided that neutrino mixing is large enough, the current ability to determine the ordering of the neutrino mass states makes the U.S. long-baseline neutrino program unique in the world.

Experiments to address these neutrino science goals will require both powerful beams and large detectors with the product of beam power and detector mass more than an order of magnitude larger than NOvA-generation experiments. Such "Phase II" experiments will require intense muon neutrino beams, regardless of detector technology and regardless of whether the detector has an off-axis or wide-band beam configuration. The discovery potential of these experiments will benefit from higher proton beam power than is presently planned. For instance, in one example examined by the BNL/FNAL study group and NuSAG, a 300 kiloton water Cerenkov detector located 0.5 degree off axis in a wide-band beam at a baseline of 1300 kilometers, the reach for observing CP violation at three sigma over 50 percent of the possible values of the CP-violation parameter δ_{CP} improves from $\sin^2 2\theta_{13} > 0.030$ to $\sin^2 2\theta_{13} > 0.012$ if the proton flux is doubled from 6.8 MW-year to 13.6 MW-year. The reach for determining that $\theta_{13} \neq 0$ and for determining the neutrino mass hierarchy also improves. NuSAG examined another example that would use two 50-100 kiloton liquid argon detectors at different baseline distances 14 mrad off-axis to existing NuMI beam, and requiring a similar proton flux.

Phase II oscillation experiments provide a longer baseline that improves sensitivity to the mass hierarchy. They also afford the opportunity to study nucleon stability with improved sensitivity. Answering the question *"Do all the forces become one?"* most likely requires a proton decay experiment with a large underground detector. The neutrino detector, if located in the Deep Underground Science and Engineering Laboratory planned by NSF, is also the detector for the proton decay experiment.

The physics reach and competitiveness of a nearer-term NOvA experiment would also improve with enhancements (beyond the planned 700 kW) to Main Injector beam power. SNuMI (an upgrade of NuMI) would increase 120 GeV proton power by approximately 70 percent. SNuMI would support a neutrino program that would be both competitive and complementary to the T2K (Tokai to Kamiokande) program based on the Japanese Proton Accelerator Research Complex. The beam power is roughly 60 percent higher than planned for Phase I of the J-PARC facility, and would remain competitive at least through the latter half of the next decade, depending on upgrades undertaken at J-PARC.

The proposed Project X would increase 120 GeV proton power by approximately 230 percent, markedly enhancing the physics reach of NOvA until a Phase II experiment is constructed. This facility would likely exceed the capabilities of the J-PARC facility, at least as currently envisioned, if it were to begin operations in the latter half of the next decade. Figure 2 presents the sensitivity of achieving a 3σ discovery of $\sin^2 2\theta_{13} \neq 0$ with running SNuMI or Project X for 3 years. Similar gains can be made by NOvA in its ability to resolve the mass hierarchy.

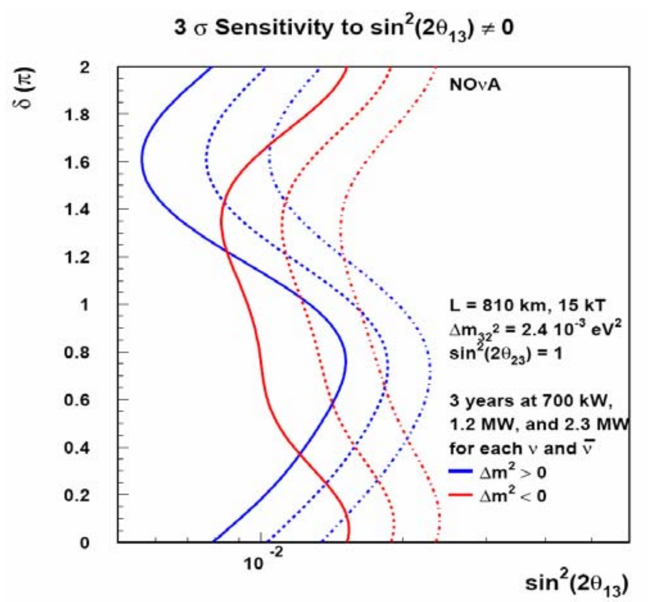

Figure 2: Ability of NOvA experiment to observe $\sin^2 2\theta_{13} \neq 0$ at 3σ significance with the planned 700 kW beam operation (dot-dashed curves), possible 1.2 MW SNuMI (dotted curves), and possible 2.3 MW Project X (solid curves). It is plotted as a function of $\sin^2 2\theta_{13}$ and δ_{CP} for normal (blue) and inverted (red) mass orderings.

While SNuMI would create a substantial improvement, Project X, with flexible beam energy and power for the generation of long-baseline neutrino oscillation experiments that will follow NOvA, would provide a dramatic boost in capability. At the optimized proton energy (50-60 GeV) for Phase II experiments, the proton beam power would be about 0.5 MW for SNuMI and about 2 MW for Project X. For a given sensitivity goal, the high-power beam would substantially reduce either the required running time or the required detector size. Or, for a given detector size and operational period, it would significantly improve physics sensitivity. Using the NOvA sensitivities as a guide, the improvement in physics reach (for example in observing $\sin^2 2\theta_{13}$ or in resolving the mass hierarchy) from SNuMI to Project X is expected to be roughly a factor of two.

Neutrino physics with 8 GeV and 800 GeV protons

The Booster neutrino beam with 8 GeV protons offers opportunities for neutrino experiments beyond the existing experiments, MiniBooNE and SciBooNE. In addition, experiments using high energy neutrinos produced in a Tevatron fixed-target neutrino beam line would become possible if the Main Injector can provide sufficient 50-120 GeV protons to feed both the long-baseline neutrino program and the Tevatron, for generating 800 GeV protons. Possible future experiments (see Appendix C for details) include:
using 800 GeV protons,

- an experiment to precisely measure the weak mixing angle

using 8 GeV protons,

- an experiment to investigate the excess of low energy electron-neutrino-like events in MiniBooNE, and to prototype detection of neutrino interactions in liquid argon time projection chambers which can also be used as a NOvA near detector,
- an experiment to measure the strange quark contribution to the nucleon spin and neutrino-nuclear cross-sections at low energies relevant to supernova core collapse, and
- an experiment to study coherent elastic neutrino-nuclear scattering.

The ability to conduct these experiments depends on the flexibility of the accelerator complex. The SNuMI design requires all Booster pulses for running NOvA. Alternatively, the Booster neutrino beam can be run for some of these experiments at a tax of approximately 15 to 20 percent. The Tevatron neutrino line results in a ~5 percent tax on NuMI, irrespective of Project X or SNuMI, due to the use of a Main Injector acceleration cycle to inject into the Tevatron. Thus, the proton source upgrades, in particular Project X, facilitate a broader physics program.

3.2 Precision Physics

Ultraprecise experiments involving muons and quarks with various flavors provide physics discovery potential for the coming decades. These experiments would complement the searches at the LHC, and could probe physics at an energy scale well beyond the reach of the LHC.

Muons

In the Standard Model, virtual neutrino mixing mediates muon and electron number violation (generically lepton flavor violation or LFV), but at a rate below the threshold of any possible experiment. However, extensions to the Standard Model could allow such processes at rates high enough for observation of new physics or to reveal limits on LFV processes significantly constraining models for new physics. A new experiment to search for muons converting to electrons in the field of a nucleus would be sensitive to rates predicted in many specific models (e.g. grand unified supersymmetry). It would detect effects due to particles at a mass scale up to 3000 TeV/c^2, for example in models with new vector bosons or leptoquarks. The mass scale that such an experiment would indirectly probe far exceeds the mass scale that the LHC or ILC will probe directly. Neither the LHC nor the ILC is likely to address the area of LFV processes. Other low-energy LFV searches (e.g. $\tau \rightarrow \mu\gamma$) are typically not as sensitive to new physics, despite larger expected branching fractions, due to the small τ flux and unavoidable backgrounds.

An intense 8 GeV proton beam and the Accumulator and Debuncher rings, available after the end of antiproton production for the Tevatron Collider program, would make possible an LFV search experiment that would make, by far, the single most sensitive search for any LFV process. The SNuMI accelerator upgrades would increase the total proton flux at 8 GeV, allowing a modest increase in beam for the muon program while also increasing the beam power available to the neutrino program. Project X would increase the beam power available to the muon program by close to a factor of 10. Reoptimizing the muon beam parameters (e.g. by decreasing the energy spread and transverse beam size) would reduce backgrounds further improving the reach.

Kaons

The ultrarare $K \rightarrow \pi\nu\nu$ process and the manifestly lepton-flavor-violating decays such as $K \rightarrow \pi\mu e$ are sensitive to Beyond the Standard Model physics with mass scales greater than 1000 TeV/c^2 in some models. The Standard Model calculation of the $K \rightarrow \pi\nu\nu$ branching fraction is very robust, with theoretical uncertainties constrained to less than a few percent. Some BSM models can enhance the Standard Model $K \rightarrow \pi\nu\nu$ rate by up to a factor of three in the charged mode and up to a factor of about 30 in the neutral mode. The excellent control of theoretical uncertainties permits 5-sigma discovery sensitivity for BSM enhancements as low as 20 percent in the charged mode and 10 percent in the neutral mode if comparable experimental sensitivity can be achieved. The current experimental state of the art for the charged mode is the CERN experiment NA48. For the neutral mode, a phased program at KEK and then J-PARC projects an improved sensitivity early next decade.

The high-intensity 8 GeV proton facilities and the Tevatron stretcher facility described in Chapter 4 represent a potential breakthrough in ultrarare kaon decay physics. These facilities can provide kaon beams of unprecedented purity and intensity to drive state-of-the-art rare-decay experiments in the next decade.

Measuring the $K^+ \rightarrow \pi^+\nu\nu$ branching fraction with a precision to match the small theoretical uncertainty could be a flagship measurement for a Fermilab flavor physics program. Such an experiment could probe many other decay channels including precision measurements of $K^+ \rightarrow e^+\nu$ and $K^+ \rightarrow \pi\mu e$ searches, both uniquely incisive probes of BSM physics. In the neutral kaon sector, a precision experiment could discover and measure the ultrarare $K^0 \rightarrow \pi^0\nu\nu$ decay process, which is very sensitive to CP-violating BSM amplitudes. It could discover or exclude several BSM models on the road to the Standard-Model-predicted $K^0 \rightarrow \pi^0 \nu\nu$ branching fraction of 3x10^{-11}. Upon acquiring the Standard Model sensitivity, the experiment would become sensitive to very-high-mass scale (>1000 TeV/c^2) and extra-dimensional models through a precision measurement of the $K^0 \rightarrow \pi^0 \nu\nu$ branching fraction.

Discovery sensitivities increase with beam power. In addition, the very large proton intensity of Project-X motivates a reoptimization of beam parameters, resulting in a simplified experiment and reduced technical risk.

Charm and hyperon physics with antiprotons:

Fermilab operates the world's most intense antiproton source, a distinction it will continue to hold even after the planned 2014 startup of the Facility for Antiproton and Ion Research in Germany. The anticipated shutdown of the Tevatron Collider program presents the opportunity for a world-leading low- and medium-energy antiproton program capable of studying a range of physics questions with unequaled sensitivity: hyperon CP violation and rare decays, charm mixing, the charmonium spectrum and recently-discovered nearby states, and CPT and antimatter-gravity tests with antihydrogen.

3.3 Summary

At the intensity frontier, the fields of neutrino science and precision flavor physics offer promising pathways to physics topics not covered by the LHC, the proposed ILC, or nonaccelerator physics. A program that could provide unique opportunities for neutrino and precision physics would serve many users and prepare future generations of U.S. particle physicists to exploit the potential of accelerator-based scientific opportunities in the U.S. and worldwide.

Chapter 4. Facilities for the Intensity Frontier

The Steering Group considered a variety of accelerator facilities and programs using the following criteria:

- Support for physics research goals;
- Effective use of Fermilab accelerator assets freed up at the end of Tevatron Collider operations;
- Alignment with the ILC R&D program;
- Potential for achievement over the next decade.

Twelve facilities received consideration based on some or all of these criteria. Appendix E sorts these facilities on the basis of relevance to proton- or electron-based programs. This chapter describes facilities that would support neutrino experiments and precision measurements described in Chapter 3. They include SNuMI, Project X, the Debuncher Slow Extraction, the Tevatron Stretcher, and a High Energy Neutrino Facility. Both SNuMI and Project X would directly increase the total proton availability at Fermilab, while the Debuncher, the Stretcher, and the High Energy Neutrino Facility would not. Table 1 summarizes the possible evolution of proton availability at Fermilab starting from the present. The first three columns represent current performance and improvements now underway. The last two columns list SNuMI and Project X parameters. All columns are based on injecting beam from the existing 8 GeV Booster, except for Project X, which eliminates the need for the Booster. While the table does not list any beam power availability at 8 GeV in SNuMI, protons could be made available at this energy at the expense of availability at 120 GeV.

Table 1. Possible evolution of proton availability at Fermilab

	Now	Proton Plan	Nova*	SNuMI	Proj X		
Batch Intensity (8 GeV)	4.40E+12	4.30E+12	4.10E+12	4.50E+12	5.63E+13		protons/pulse
Rep Rate	7	9	12	13.5	5		Hz
Protons/hour	1.11E+17	1.39E+17	1.77E+17	2.19E+17	1.01E+18		
Main Injector batches	7	11	12	18	3		
MI batches to pbar target	2	2	0	0	0		
MI Cycle Time	2.4	2.2	1.33	1.33	1.4		sec
MI Beam Power (120 GeV)	**176**	**338**	**710**	**1169**	**2314**		kW
8 GeV Beam Power (available)	**18**	**17**	**16**	**0**	**206**		kW
Injection energy (1st synch)	400	400	400	400	8000		MeV
$\beta\gamma^2$	1.45	1.45	1.45	1.45	90.30		
Injection emittance	10	10	10	10	20		πmm-mr
Injection space charge tune shift	0.23	0.22	0.21	0.23	0.07		
*Nova column includes a potential upgrade of the Booster repetition rate to support simultaneous							
delivery of ~2E20 protons/year at 8 GeV. Nova itself requires Booster operations at 9 Hz.							

4.1 SuperNuMI (SNuMI)

SNuMI uses antiproton facilities freed up at completion of the Tevatron Collider program to develop a more intense proton source for NuMI. The Antiproton Accumulator would momentum-stack protons delivered from the Booster. The momentum-stacking process is inherently more efficient in its use of longitudinal phase space than the “slip-stacking” process used through the NOvA era. This increased efficiency supports the higher proton throughput of SNuMI.

The SNuMI scheme momentum-stacks three Booster batches in the Accumulator and then transfers them to the Recycler. This process repeats six times via “boxcar” stacking in the Recycler. A single shot transfers the Recycler proton load to the Main Injector. The result is the transfer of 18 Booster batches to the Main Injector. Because the Booster cycles at 15 Hz, the Recycler accumulation process takes 1.33 seconds. The accumulation process takes place while the Main Injector is accelerating, fast extracting beam to the neutrino target, and ramping down for a new load. A 1.33 second cycle time leads to a beam power of 1.2 MW. Since this scheme uses all available Booster cycles, no additional protons are available for an 8 GeV program without diversion from the Main

Injector. However, SNuMI is compatible with reconfigurations of the Debuncher ring and/or the Tevatron to support slow spill programs at 8 or 120 GeV respectively, and with the Tevatron High Energy Neutrino Facility.

SNuMI could probably be constructed over a two-to-three-year period following completion of Tevatron Collider operations. While it would accomplish some of the scientific goals, this plan requires continued use of the existing 8 GeV Booster and 400 MeV Linac accelerators, which date from the 1972 start of beam operations at Fermilab. These accelerators' aging components have led to reliability issues over recent years. Thus, SNuMI entails some risk of operational down time or failures, and does not invest in a longer-term program of experiments.

4.2 Project X

Project X is based on an 8 GeV superconducting H^- linac. The downstream 6 GeV would use ILC cryomodules and RF distribution systems, with perhaps some modifications in the transverse focusing arrangement. The front end draws heavily on technology developed for the Advanced Exotic Beam Laboratory.

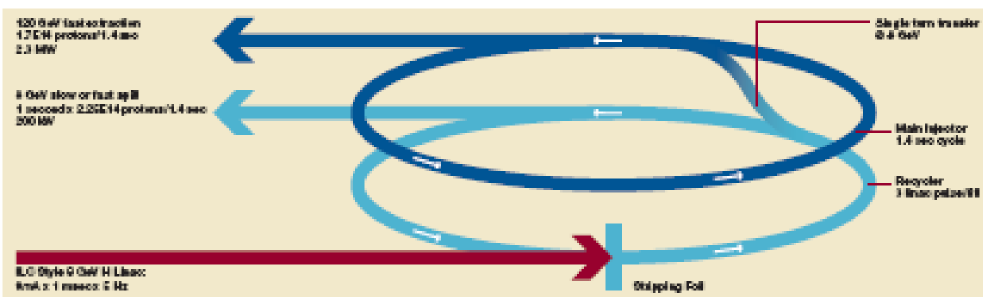

Figure 3. Schematics of Project X

Figure 3 schematically displays the basic scenario. Using the Recycler as a stripper and accumulator ring is the key element that allows the linac to run with the same beam parameters as the ILC. The linac operates at 5 Hz with a total of 5.6×10^{13} H^- ions delivered per pulse. They are injected into the Recycler using a standard H^- stripping procedure. The total pulse length (1 ms) implies 100-turn injection. The injection process "paints" the beam both transversely and longitudinally to reduce space charge forces. Following the 1 ms injection, the orbit moves off the stripping foil and circulates for 200 msec, awaiting the next injection. Following three such injections a total of 1.7×10^{14} protons are transferred on a single turn to the Main Injector. These protons are then accelerated to 120 GeV and fast extracted to a neutrino target. The Main Injector cycle takes 1.4 seconds, leading to a beam power at 120 GeV in access of 2 MW. However, since the loading of the Recycler only requires 0.6 seconds, this leaves 0.8 seconds (four linac beam pulses) for accumulation and/or distribution of protons from the Recycler at 8 GeV. The total 8 GeV beam power is significant (200 kW). Different configurations of the Recycler could distribute this beam in any combination of fast or slow extractions required by the physics program. Project X is also compatible with reconfigurations of the Tevatron to support a 120 GeV slow spill or with the high-energy neutrino program.

Both would come with a modest cost in protons delivered to the neutrino program at 120 GeV, because of the use of a Main Injector cycle to transfer beam to the Tevatron.

Project X would substantially increase the capabilities of 120 GeV test-beam program and would support the test-beam infrastructure of the laboratory through the construction of new beamlines driven by the 8 GeV linac. These new test beams could provide 8 GeV protons and electrons with the exact ILC beam-time structure, of interest to the ILC detector community for evaluation of readout strategies and low-energy calorimeter performance.

Taking full advantage of the increased beam power available from Project X would require changes to the Recycler, the Main Injector, and the neutrino target. The Recycler would require a new H^- injection system and probably measures to mitigate electron cloud effects. It would also require a new (fast or slow) extraction system, and new RF systems. The Main Injector would need a new RF system, a gamma-t jump, and measures to mitigate electron cloud effects. Project X would require design and construction of a new neutrino target station to support 2.3 MW operations. Opportunities exist for construction of a spur off the current NuMI line to permit directing a beam towards the DUSEL site. A significant R&D program would be associated with this effort.

The accelerator portion of Project X would be comparable in size and scope to the Main Injector. Construction would take four to five years with a few hundred FTEs per year. It would be most effectively achieved as an interlaboratory collaboration centered at Fermilab.

4.3 Debuncher Slow Extraction

The Antiproton Debuncher ring could provide an 8 GeV slow extraction facility with parameters that would be appropriate to a muon-to-electron conversion experiment. The Debuncher could take one of six sets of Accumulator batches. A h=1 RF system within the Debuncher would capture the proton load, and a slow extraction system would spill the beam over the ~1.33 second cycle time. Operating with this single bunch, the circumference of the Debuncher creates a spill structure containing a short pulse every 1.6 μsec. Total delivered beam in this scenario would be 1.35×10^{13} every 1.33 seconds, with a corresponding 16 percent reduction in available protons at 120 GeV. The diversion of protons could decrease according to programmatic considerations.

4.4 Tevatron Stretcher

Taking protons at 120 GeV directly from the Main Injector, the Tevatron could be converted to a 120 GeV "stretcher" ring to provide very high (>90 percent) duty factor beams for a variety of precision frontier experiments. The Tevatron Stretcher provides an independent program that could be used with or without intensity upgrades. However, the program would result in a "tax" on the Main Injector-based neutrino program.

A possible scenario would use two Main Injector cycles, at 3.75×10^{13} protons per pulse, providing 7.5×10^{13} protons in the Tevatron at 120 GeV. This beam is not accelerated, but rather is slow extracted over roughly 60 seconds. The duty factor would approach 95 percent. This scenario would deliver a total of about 3×10^{19} protons in a year, representing a ~5 percent diversion of protons from the SNuMI or Project X neutrino program. The delivered intensity would be about a factor of 2.5 beyond the highest intensity ever stored in the Tevatron. The laboratory would need to address a number of intensity-related issues. In addition, this scheme would require the design and implementation of a 120 GeV resonant extraction system.

The Tevatron Stretcher and associated extracted beam lines would require a one-to-two year construction period at an appropriate time following completion of Tevatron Collider operations.

4.5 High Energy Neutrino Beam

The Tevatron could operate at high intensity and high energy in fixed target mode. The science program described in Chapter 3 and Appendix C would require a minimum beam energy of roughly 800 GeV, with a delivered intensity of at least 4×10^{19} protons per year. The maximum cycle rate of the Tevatron in fixed target mode is about 40 seconds, establishing the basic per-pulse intensity requirement.

A possible scenario would be similar to the Stretcher scheme described above. Two Main Injector cycles, at 3.75×10^{13} protons per pulse, are transferred to the Tevatron at 120 GeV. This beam is accelerated and delivered to a neutrino target via a fast spill mechanism. Based on a minimum Tevatron cycle time of 40 seconds, the scheme would deliver a total of about 4×10^{19} protons per year, representing a ~5 percent diversion of protons from the SNuMI or Project X neutrino program. The same intensity issues associated with the Tevatron stretcher would apply here. Several other technical issues would also require resolution, including: 1) development of the fast extraction scheme; 2) mechanisms for loss control and collimation; 3) recommissioning of the CZero high intensity abort; 4) a reliability analysis.

Tevatron fixed target operations would require one to two years of implementation work at an appropriate time following completion of Tevatron Collider operations.

4.6 Facilities to support ILC R&D and Fermilab as a potential host site

Among the proton facilities that the Steering Group considered, Project X is unique in supporting ILC development at Fermilab. It would drive the initial stage of industrialization of cryomodules and provide experience with operating the linac as a complete system. Such roles could advance the ILC if a delay in a decision to construct slowed progress in industrialization.

Industrialization

ILC cryomodules are the single most complex and expensive technical element of the ILC. Development of the national and institutional capability to build and test cryomodules with ILC specifications is among the highest priorities of the GDE Americas Regional Team and of Fermilab in its bid to host the ILC. The DESY experience has shown that mastery of this technology requires significant infrastructure investments and a long learning curve for personnel.

Project X requires approximately 36 β=1 ILC style cryomodules. Production over a three-year period represents a significant advance over capabilities currently anticipated by the Americas Regional Team. However, such a production rate is below ILC requirements, so Project X would represent the initial phase of an industrialization buildup for ILC in the U.S. Full integration within an ILC industrialization plan requires more study.

Operational Experience and Systems Testing

As described in Chapter 4.2, Project X could be configured to use the same beam parameters as the ILC (9 mA × 1 msec × 5 Hz). The linac design calls for 31.5 MV/m but could operate successfully at lower gradients. The RF generation and distribution system would be the same as ILC's, giving valuable experience with the klystrons, modulators, couplers, and cryomodules under operational conditions. How much the focusing arrangement, i.e. distribution of quadrupoles through the cryomodules, can be made identical to ILC's is currently under study. However, this element is probably not critical.

Operation of the linac with electrons is also under study. It will require a mechanism to provide appropriate phasing of the cavities to compensate for the electrons being fully relativistic. Ferrite-based vector modulators, currently under development, could provide this capability. Operation with electrons at the full ILC specification would provide important understanding of higher-order modes and associated loads on the cryogenic system.

4.7 Facilities to support Longer Term Possibilities

Chapter 5 describes long-term facilities. However, it is worth noting that the high-power 8 GeV beam of Project X would support a program aimed at the development and demonstration of technologies required for muon-based storage rings such as a neutrino factory or muon collider.

Chapter 5. Energy Frontier Accelerators beyond the ILC and LHC

The Steering Group developed the steps necessary to explore higher-energy colliders that might follow the ILC or that might be needed should the results from LHC point toward a higher energy than that planned for the ILC. Steps to explore higher-energy hadron and

e^+e^- colliders are currently underway, with results expected within five years. The exploration of a muon collider is a far different matter and will require considerable attention and significantly increased resources.

5.1 Hadron and e^+e^- Colliders

LHC Energy Upgrade: Magnet technology needed to upgrade the LHC to 21 TeV Center-of-Mass energy is currently under development as part of the LHC Accelerator Research Program, or LARP, and of the DOE base funding for magnet technology development. This technology should be ready for application in about five years.

Very Large Hadron Collider (VLHC): Likewise, the basic technology that could support construction of a VLHC will be in hand on a five-year time scale should it be needed. Detailed magnet development would need to follow a reanalysis of the energy and optimum size of the machine once the physics objectives clarify. Luminosity will be a challenge if it is to increase beyond that planned for the LHC in proportion of E^2 as required to follow energy dependence of the physics cross section.

Compact Linear Collider (CLIC): The current CERN midterm plan includes efforts to demonstrate the CLIC technology for an e^+e^- collider up to 3 TeV by 2010.

5.2 Muon Collider

In contrast to the situation for electron and hadron colliders, demonstrating the viability of a muon collider will require many steps:

- exploration of various possible overall schemes,
- a specialized proton driver,
- various targeting and capture and phase rotation schemes,
- various possible six-dimensional (6D) ionization cooling configurations,
- various methods of acceleration to high energy of the cooled muons,
- storage ring designs, and
- detector configurations.

Each of these steps may involve development of more than one technology. Given the many unknowns, it is not possible to predict with confidence when these explorations could be complete. In a technically limited schedule, the 6D cooling exploration would pace the overall result. Significant trial of the current ideas could be ready in five to 10 years.

Overall Scheme: The “front end” of a muon collider and that of a neutrino factory have much in common. As neutrino factory work to date has shown, it is useful to develop an end-to-end design to illuminate the further simulation, design and hardware R&D needed for development of a facility, for deriving early cost estimates, and for evaluating viability. Such exercises have been carried out.

Proton Driver: To achieve luminosities $O(10^{34}cm^{-2}s^{-1})$ requires proton power on target of ~ 4 MW in the form of ~3 ns-long bunches each with $O(10^{14})$ protons. This driver would be an upgrade of Project X. Some accumulator, from an appropriate source, with fast extraction would need development.

Targeting, Capture and Phase Rotation: While several multimegawatt target developments have been carried out, each has special features, and the muon collider target is no exception. An international experiment is now underway using a mercury jet and the requisite peak proton intensity. Other, safer, target schemes need further investigation. Capture and phase rotation require very high field solenoids and low frequency cavities or induction accelerator units that can operate in magnetic fields, all of which need R&D.

6D Ionization Cooling: Ionization cooling is a key process for both the neutrino factory and muon collider. The neutrino factory requires only transverse cooling (4D) by about a factor of 100 in the phase space area to produce a useful neutrino beam. A muon collider, however, requires a 6D phase space volume reduction of 10^6. So far, neither has been demonstrated, although a 4D cooling experiment construction is now about three years from data taking. Current ideas envision three different configurations for performing the 6D cooling, but no complete experiment testing any of them is yet designed or under construction. All schemes use high magnetic fields and high gradient cavities, preferably immersed in high magnetic fields together with energy loss cells (dE/dx) separate or incorporated into the reaccelerating cavities. All of these items require performance well beyond the current state of the art.

Reacceleration: After cooling, the muons must be rapidly accelerated to the full collision energy. Schemes using linacs, recirculating linacs, fixed-field alternating-gradient accelerators, pulsed synchrotrons and combinations of these have been suggested. High-gradient, relatively low-frequency superconducting cavities and other accelerator technology beyond today's practice require design and development in an iterative cycle with system design to understand the optimum approach and cost for a given target luminosity.

Collider Ring: Maximizing the luminosity requires a very-high-magnetic-field storage ring formed of magnets with great radiation tolerance. Both conditions are far from current practice and would require a concerted design and development program for feasibility and economic assessment. The design of the focusing lattice is also very challenging in its demand for low-momentum compaction and high-momentum acceptance.

Detector: Besides the challenges of detection in a high-luminosity lepton environment, a muon collider detector must deal successfully with a very high radiation background caused by the muon decay electrons. This problem has received some consideration in the past, but the advances of detector technology – and demand – require continuing reevaluation.

Program Elements: In addition to the several technology R&D matters that require resolution for an evaluation of muon collider viability, extensive simulation and design activities are required. Some technology R&D items are

- high-field magnets, including solenoids, dipoles and quadrupoles, with the development of accompanying superconducting materials, including high temperature superconductor material
- high-gradient RF cavities, both normal and superconducting, of various frequencies with normal-conducting cavities immersed in magnetic fields;
- liquid or high pressure gaseous hydrogen or LiH dE/dx cells, and
- auxiliary technologies.

Simulation and design work is required across the board and is often neglected in evaluating needed resources.

Current Activities: A worldwide collaboration currently looking at neutrino factories expects to issue a report in 2012 reviewing the physics as it appears then and presenting possibilities for discovery. Currently the international MERIT experiment at CERN is exploring the mercury jet production target at the needed peak power level. In the U.S., physicists have formed the Neutrino Factory and Muon Collider Collaboration (NFMCC) of laboratory and university scientists. Together with international partners, NFMCC is performing the MUCOOL activities at Fermilab to develop muon cooling technologies, and coordinating U.S. participation in the MICE experiment at Rutherford Appleton Laboratory to carry out a 4D ionization cooling and demonstration project. In addition, Fermilab has commissioned a Muon Collider Task Force to explore long-term prospects of a muon collider. While all of these efforts have worthy goals, their aggregate scale has steadily declined and is now unlikely to achieve a useful evaluation of muon collider feasibility, and potential schedule and cost in a timely fashion.

Schedule and Cost: As the difficulties that will arise in mastering 6D ionization cooling remains unknown, it is not possible to state even a technically limited schedule with any precision. However, a significant evaluation of cooling and other feasibility items might be carried out in approximately five to seven years given support for a technically limited schedule. A rough comparison with the U.S. ILC development intensity prior to the ITRP decision would indicate the need for a minimum of $20M annually and 100 FTE of appropriate skills. Of course, in the event of a decision to proceed, an integrated plan with a detailed cost and personnel resource estimate should be the first order of business. It should also be noted that the entire activity need not be carried out at Fermilab, but that other willing partners in U.S. labs and universities are ready to engage. It would be very advantageous to have more than one muon test facility to carry out cooling and the associated technologies in a collaborative and coordinated fashion.

5.3 Conclusions

The Steering Group recommends a strengthening of the R&D program for future accelerators over the next five years independent of the ILC timeline. A construction start for the ILC early in the next decade would dictate reevaluation and adjustment of the effort as appropriate. If the ILC were built offshore, and if a satisfactory cooling method and a concept design for the collider system have emerged, the muon collider effort could rapidly ramp up.

Chapter 6. A Fermilab Plan for Discovery

The Steering Group has adopted a number of guidelines in forming the plan.

1. The LHC program is our most important near-term project given its broad science agenda and potential for discovery. It is essential to support the physics analysis, computing, and accelerator and detector upgrades.

2. The particle physics community's highest priority for investment toward the future is the ILC, based on our present understanding of its potential for breakthrough science. Fermilab will continue to participate vigorously in the international R&D program for the ILC and to be one of the leaders in the global ILC effort. The laboratory will strive to make the ILC at Fermilab a reality by accomplishing the preparatory work required for the U.S. to bid to host the ILC.

3. There must be an intermediate science program in case the timeline for ILC is stretched out. This program will be an opportunity to do exciting physics that complements discoveries at energy frontier facilities, and to make further progress on ILC technology. The program should provide great discovery potential, support the ILC R&D and industrialization as well as R&D on future accelerators beyond the ILC and LHC, and strengthen ties with the university community and with other laboratories. The plan must be robust and flexible.

4. Fermilab will continue a phased program to study dark matter and dark energy through astrophysical observations. The program will allow complementary discoveries to those expected at the accelerator-based particle physics programs. These non-accelerator-based efforts are outside the Steering Group's charge, and not included in the plan.

Based on these planning guidelines, the Steering Group recommends the following plan for the accelerator-based particle physics program at Fermilab.

- Fermilab's highest priority is discovering the physics of the Terascale by participating in LHC, being one of the leaders in the global ILC effort, and striving to make the ILC at Fermilab a reality.
- Fermilab will continue its neutrino program with NOvA as a flagship experiment through the middle of the next decade.

- If ILC remains near the GDE-proposed timeline, Fermilab will focus on the above programs.

- If ILC departs from the GDE-proposed timeline, Fermilab should pursue additional neutrino science and precision physics opportunities by upgrading the proton accelerator complex.
  - If ILC start must wait for a couple of years, the laboratory should undertake the SNuMI[4] project.
  - If ILC postponement would accommodate an interim major project, the laboratory should undertake Project X[5] for its science capability and ILC alignment.
- If ILC is constructed offshore, Fermilab should pursue additional neutrino science and precision physics opportunities by upgrading current proton facilities while supporting the ILC as the highest priority.
  - The laboratory should undertake SNuMI at a minimum.
  - Or the laboratory should undertake Project X if resources are available and ILC timing permits.

- In all scenarios,
  - R&D support for Project X should be started now, emphasizing
    - expediting R&D and industrialization of ILC cavities and cryomodules
    - overall design of Project X
  - R&D for future accelerator options concentrating on neutrino factory and muon collider should be increased.[6]
  - The laboratory should support detector R&D and test beam efforts for effective use of future facilities.

The Steering Group plan gives the highest priority to energy-frontier physics with the LHC and the ILC, as discussed at length elsewhere. In the event that SNuMI or Project X is realized, a broad range of new experiments would become possible, pursuing fundamental questions of physics via various pathways. The physics opportunities fall roughly into two categories: neutrino science at the intensity frontier and precision physics at the intensity frontier. The potential breadth, depth and scale diversity of this experimental program make the Steering Group plan flexible and robust. Through the laboratory and HEPAP advisory process, each experiment would eventually be judged on its physics merits at the appropriate time.

Neutrino Science at the Intensity Frontier

A future neutrino program capable of fully resolving whether muon neutrinos oscillate into electron neutrinos, the nature of the neutrino mass hierarchy, and whether CP violation occurs in the neutrino sector will require more intense beams

[4] SNuMI is an upgrade of NuMI.
[5] Project X consists of an 8 GeV ILC-like linear accelerator and reconfigurations of the existing Recycler and Main Injector. The accelerator portion would be similar in size and scope to the Main Injector. Construction would take four to five years with a few hundred FTEs per year. It would be most effectively mounted as an inter-laboratory collaboration centered at Fermilab.
[6] The total annual U.S. R&D budget needed for the neutrino factory and muon collider is estimated to be approximately $20M.

and larger or better detectors than are presently available. This is by necessity a staged program that in all its branches requires a more intense neutrino beam. The early stages of this program can be carried out with NOvA, but ultimately a far-term neutrino program could be best defined by a flagship experiment consisting of a wideband beam targeting a large detector at DUSEL. This would demand a high-intensity proton beam in the range that Project X could deliver. The neutrino detector in the DUSEL could also be the detector for a proton decay experiment.

Beyond this horizon, Project X could create a pathway toward a muon storage facility to produce intense ν_μ and ν_e beams, which would be needed for the neutrino-oscillation and CP-violation program in case $\sin^2 2\theta_{13}$ is extremely small. This could also be a crucial step along the way to regaining the energy frontier in the U.S. by way of a muon collider, and relying upon Project X as a muon source, followed by muon cooling.

High-intensity protons from Project X could be used for a diverse program with neutrino beams. Reconfigurations of the existing accelerator complex would create proton beams at various energies, including 8 GeV, 120 GeV and 800 GeV, and could support a variety of small-scale experiments. The possibilities include experiments measuring the weak mixing angle via muon neutrino scattering on electrons to probe the Standard Model via precision measurements; highly sensitive neutrino scattering experiments using liquid argon technology, of interest for future long-baseline physics; nuclear structure experiments measuring neutrino's neutral-current elastic scattering to resolve outstanding questions in nuclear structure.

Precision Physics at the Intensity Frontier

The availability of an intense 8 GeV proton beam would provide the capability to search for lepton-flavor violation with sensitivity that is orders of magnitude beyond that of current experiments. Such an experiment, a muon-to-electron conversion experiment, by far the single most sensitive search for any lepton-flavor-violation process, could begin to operate before completion of Project X in a baseline sensitivity mode and continue with Project X with a dramatic improvement.

The study of rare decays of kaons likewise admits a natural phase I and phase II construction. In the early phase, a high-intensity 8 GeV proton facility and the Tevatron Stretcher facility would provide potential for breakthroughs in ultrarare kaon-decay physics in next-generation experiments. Project X could provide kaon beams of unprecedented intensity that could support state-of-the-art rare-decay experiments beyond the next decade. These processes are sensitive to new physics with energy scales in excess of 1000 TeV.

Fermilab operates the world's most intense antiproton source and could continue to hold this position, addressing with unequaled sensitivity a range of physics questions, including hyperon CP violation and rare decays, charm mixing, the charmonium spectrum and recently discovered nearby states, and CPT and antimatter-gravity tests with antihydrogen.

An intense proton facility such as Project X would offer a world-class experimental program to the U.S, support the ILC and hosting the ILC in the U.S. if the ILC departs from the GDE-proposed timeline, and align with the early phases of muon collider development, placing the field on the path to the energy frontier beyond the ILC. The physics program with the intense proton source offers strong opportunities for discovery, following alternate pathways to those offered by the LHC and ILC for answering Quantum Universe questions. It would serve many scientific users and prepare future generations of U.S. particle physicists. The potential breadth, depth, scale and diversity of this experimental program and the facility's supporting role for the ILC and future energy frontier accelerators make the Steering Group plan flexible and robust.

Fermilab and ILC

ILC Accelerator Activities

Fermilab's International Linear Collider and Superconducting Radio Frequency program is coordinated with the ILC-GDE and respects U.S. regional priorities. Fermilab's ILC effort focuses on the main linac, based on SCRF technology, and the design of conventional facilities, which are the largest cost drivers of ILC. Key elements of Fermilab's main linac program include cavity and cryomodule fabrication and testing with and without beam, related infrastructure development, advancing U.S. industrial capabilities, and developing designs and technologies to improve ILC performance and reduce cost. A collaboration of U.S. institutions under the leadership of the American Regional Team of the GDE is carrying out the U.S. ILC R&D program. This program plans to build and install SCRF infrastructure at U.S. laboratories including Fermilab. Fermilab has contributed substantial laboratory resources to build up its SCRF infrastructure. The overall goal is to advance the ILC and to establish the U.S. and Fermilab as a credible and qualified host of ILC. The technical goals are:

- Develop cavity processing parameters for a reproducible cavity gradient of 35 MV/m; improve the yield of 9-cell cavities at 35 MV/m in vertical tests. Carry out parallel and coupled R&D on cavity material, fabrication, and processing to identify paths to success.
- Assemble and test several cryomodules with average gradient > 31.5 MV/m.
- Build and test one or more ILC RF units at ILC beam parameters, high gradient, and full pulse rep rate. Prepare plans for and participate in ILC Main Linac System Test consisting of several RF units.
- Prepare infrastructure and test facilities to support continued development of cryomodules and to qualify industrially built Main Linac components and cryomodules.

The American Regional Team of the GDE has fabricated and treated SCRF cavities for various SCRF-based projects. The U.S. ILC effort is expanding cavity-fabrication capability in industry and installing cavity processing facilities to fulfill the needs of ILC R&D. The goal for ILC cavities is 95 percent yield at 35 MV/m. The U.S. goal is to fabricate, process, and vertically test about 100 cavities per year, supporting the development of U.S. industrial capability. Thomas Jefferson National Accelerator Facility and Cornell University currently provide modest cavity-processing and testing capacity. New process and test infrastructure under construction at ANL and FNAL should allow the U.S. to meet its goal by 2009. This would allow ILC to settle on an acceptable process and yield in about two years.

To complete the range of capabilities necessary for establishing core ILC technology in the U.S., Fermilab is installing infrastructure to test dressed cavities with high-power RF, a cryomodule fabrication facility, and an RF unit test facility to test cryomodules with an ILC-like beam.

Fermilab leads the effort to design a cryomodule for the ILC. Current efforts include moving the quadrupole to the center of the cryomodule to reduce vibration; developing cryogenic pipe sizes to support higher gradient cavities; and designing longer cryogenic strings, symmetric cavity end-groups and a new tuner. Fermilab plans to build three cryomodules by the end of FY 2010, assemble them into a single RF unit and test them at the test facility. While this is an important milestone, preparation of the U.S. to build the ILC requires building tens of cryomodules in the U.S. and developing the industrial capability to produce hundreds.

In the Engineering Design phase of the ILC, Fermilab has committed to provide key engineers and scientists to develop the design of ILC. In addition, Fermilab plans to work with U.S. industry to improve cavity and cryomodule design. Accelerator physics design and simulation of the machine will continue with a focus on emittance preservation. While working with the worldwide ILC collaboration on the ILC machine design and global site development, Fermilab has special responsibilities to develop a Fermilab site-specific design for ILC.

Physics and Detector R&D Activities

Fermilab's ILC detector R&D program is consistent with the detector R&D priorities established by the World-Wide Study group. Focusing on the most demanding aspects for the ILC detectors in collaboration with other laboratories and universities, the program consists of three areas of detector design that are well matched to Fermilab's core competencies. This research is intended to have a broad "horizontal" approach, not limited to a single ILC detector concept.

The main focus is on silicon detectors, deployed either as pixel detectors or tracking detectors. The growing demands on detectors for ILC experiments require novel solutions of semiconductor detectors characterized by improved parameters in terms of granularity, readout speed, radiation hardness, power consumption and sensor thickness. A current trend in the field of highly segmented ionizing radiation detectors is the development of Monolithic Active Pixel Sensors, which allow integration of a pixel detector and readout electronics in one entity. Fermilab developers are going beyond the MAPS approach and are vigorously pursuing "vertical integrated systems" with through-silicon via technology in a Silicon On Insulator process. This technology, whose development is driven by industry, holds enormous promise for providing low-mass, low-power particle physics detectors. An integrated approach simultaneously studies the sensor technology and the mechanical design of vertex detectors as well as tracking detectors. The primary goal is to establish the proof of principle of each technology on a timescale compatible with the start of construction of the accelerator.

A second emphasis is on the characterization of Pixelated Photon Detectors, a new development for photon detection. These PPDs consist of a pixelated silicon substrate, where each pixel operates as an avalanche photo-diode in Geiger mode. These devices hold a promise of replacing the photo-multiplier tubes. The devices are fast, operate at room temperature at modest bias voltages, and are insensitive to magnetic fields. Fermilab is working, in close collaboration with universities, on the characterization of these devices and on their applicability as photon-detectors for use in dual-readout calorimeters and scintillator-based muon detection systems.

A third focal point is the development of a test beam infrastructure. The ILC detectors are precision instruments using technologies never before employed in large-scale systems. Test beams will constitute a critical step in establishing the ILC detector technologies. In 2006, Fermilab upgraded its test beam facility largely to satisfy the needs for the ILC. As a candidate host laboratory for the ILC and with limited availability of test beams at other laboratories over the course of the next few years, we intend to enhance the test beam facilities to accommodate the needs of the whole user community.

All detector R&D builds on Fermilab's unparalleled infrastructure and expertise. As a candidate host laboratory, Fermilab intends to increase the laboratory's effort in hosting ILC-related activities including collaborative work on detector R&D and test beam facilities and strengthening its role in supporting users. . The laboratory will foster a lively and diversified program of R&D projects, for their significance for crucial and cutting-edge technology developments related not just to the ILC but also to the principal themes of world-wide research in particle and astroparticle physics. The laboratory will foster synergies among projects to optimize the scientific output for an intense, cost-effective, goal-oriented research program in collaboration with universities and other laboratories. Fermilab will continue to make the compelling case for ILC physics and to communicate with many audiences to strengthen the laboratory's leadership role in the ILC enterprise.

Appendix A. Steering Group Charge and Membership

In his remarks to HEPAP, Undersecretary Orbach requested a dialog with the HEP community: *"In making our plans for the future, it is important to be conservative and to learn from our experiences. Even assuming a positive decision to build an ILC, the schedules will almost certainly be lengthier than the optimistic projections. Completing the R&D and engineering design, negotiating an international structure, selecting a site, obtaining firm financial commitments, and building the machine could take us well into the mid-2020s, if not later. Within this context, I would like to re-engage HEPAP in discussion of the future of particle physics. If the ILC were not to turn on until the middle or end of the 2020s, what are the right investment choices to ensure the vitality and continuity of the field during the next two to three decades and to maximize the potential for major discovery during that period?"*

With the encouragement of the Office of Science and the support of Professor Mel Shochet, the chair of HEPAP, Fermilab will develop a strategic roadmap for the evolution of the accelerator-based HEP program, focusing on facilities at Fermilab that will provide discovery opportunities in the next two to three decades. This roadmap should keep the construction of the ILC as a goal of paramount importance. To guide this proposal, the Fermilab Director has appointed a Steering Group consisting of members from Fermilab and the national particle and accelerator physics community to insure that the plan serves national needs. The Steering Group will also engage additional constituents in the analysis of the various physics opportunities.

The Steering Group will build the roadmap based on the recommendations of the EPP2010 National Academy report and the recommendations of the P5 subpanel of HEPAP. The Steering Group should consider the Fermilab based facilities in the context of the global particle physics program. Specifically the group should develop a strategic roadmap that:

1. supports the international R&D and engineering design for as early a start of the ILC as possible and supports the development of Fermilab as a potential host site for the ILC;
2. develops options for an accelerator-based high energy physics program in the event the start of the ILC construction is slower than the technically-limited schedule; and
3. includes the steps necessary to explore higher energy colliders that might follow the ILC or be needed should the results from LHC point toward a higher energy than that planned for the ILC.

I am asking Deputy Director Kim to chair the Steering Group. Any recommendations that might be relevant to the FY09 budget should be transmitted as early as possible. The Steering Group's final report should be finished and delivered to the Fermilab Director by August 1, 2007. This deadline would allow for presentations to the DOE and its advisory bodies before the structuring of the FY2010 budget.

Steering Group Membership

Eugene Beier
University of Pennsylvania
geneb@HEP.upenn.edu

Sally Dawson
Brookhaven National Laboratory
dawson@bnl.gov

Young-Kee Kim, Chair
Fermilab and University of Chicago
ykkim@fnal.gov

Thomas Himmel
Stanford Linear Accelerator Center
thimel@slac.stanford.edu

Andrew Lankford
University of California, Irvine
ajlankfo@uci.edu

Tor Raubenheimer
Stanford Linear Accelerator Center
tor@slac.stanford.edu

Maury Tigner
Cornell University
mt52@cornell.edu

Joel Butler
Fermilab
butler@fnal.gov

Helen Edwards
Fermilab
hedwards@fnal.gov

David McGinnis
Fermilab
mcginnis@fnal.gov

Steve Holmes
Fermilab
holmes@fnal.gov

Sergei Nagaitsev
Fermilab
nsergei@fnal.gov

Vladimir Shiltsev
Fermilab
shiltsev@fnal.gov

Hendrick Weerts
Argonne National Laboratory
weerts@anl.gov

Appendix B. Community Input on the Physics Opportunities

The Fermilab Steering Group was called by Director Pier Oddone in March, 2007. Subsequently, subgroups were formed to advise the Steering Group on the best physics opportunities that could be exploited at the new facilities under consideration. These subgroups were composed of members of the US HEP community, and drew upon university and laboratory scientists from within and outside of the Fermilab community.

To obtain input from a broad spectrum of the US particle and accelerator physics community, a number of steps were taken. Deputy Director Kim gave presentations and conducted "town hall" style sessions at meetings of all the major collaborations at Fermilab (CDF, DZero, MINOS, MINERvA, MiniBooNE, SciBooNE, NOvA), at US CMS and ILC TTC meetings, at the June 6-7 Annual Users Meeting of Fermilab, at the June 7 Users Meeting at SLAC, and at major laboratory seminars (ANL, BNL, and SLAC), and has communicated to the US particle and accelerator community through the DPF and DPB. These sessions advised the community of the Steering Group's purpose, the process it would follow, and the mechanism by which it planned to advise the Fermilab Director, and to provide input to P5, HEPAP, and the funding agencies. In addition, the Steering Group invited input on physics possibilities from the community either in the form of letters or in brief, 1-page, expressions of interest. In its two months of existence, the Steering Group received over 16 expressions of interest and 7 letters. Input from the community has demonstrated that there is broad community interest in having a domestic facility which enables a strong US accelerator-based program.

Fermilab has a long history of community input into its physics program and in years past has held numerous Summer Studies to consider the best options for the new accelerators being developed at the Laboratory. Given the short time available for the Steering Group report, such a Summer Study was not possible, but will be conducted once the decision to provide R&D support for Project X goes forward. The full span of physics enabled by the proposed high-intensity source will be the subject of a future formal call for proposals. The precise prioritization of such experiments, however, will be elucidated by the Fermilab PAC, and advisory panels such as P5 and HEPAP convened by the funding agencies.

Neutrino Physics Group

Eugene Beier (University of Pennsylvania)
Deborah Harris (Fermilab)
Edward Kearns (Boston University)
Boris Kayser (Fermilab)
Sacha Kopp (University of Texas, Austin)
William Louis (Los Alamos Laboratory)

Precision Physics Group

Joel Butler (Fermilab)
Brendan Casey (Brown University / Fermilab)
Sally Dawson, Chair (Brookhaven National Laboratory)

Christopher Hill (Fermilab)
Daniel Kaplan (Illinois Institute of Technology)
Yury Kolomensky (UC Berkeley / LBNL)
Andrew Lankford, Chair (University of California, Irvine)
William Molzon (University of California, Irvine)
Kevin Pitts (University of Illinois, Urbana-Champaign)
Frank Porter (Caltech)
Robert Tschirhart (Fermilab)
Hendrick Weerts (Argonne National Laboratory)

Appendix C. Neutrino Science with 8 GeV and 800 GeV Protons

This section lists experiments with neutrino beams that could be carried out at the proton facility. Possible long-baseline programs for neutrino oscillation and CP violation are excluded.

Neutrino Science Experiments with 8 GeV Protons

The excess of low energy electron-neutrino-like events recently observed by MiniBooNE must arise either from new physics, not compatible with simple 2-flavor oscillations, or from a new kind of background that is of importance for oscillation experiments operating in this energy range. An experiment dubbed microBooNE with excellent low energy sensitivity provided by a liquid argon time projection chamber (LArTPC) is proposed to study individual final states producing events in the region of excess. This experiment would also be an extremely valuable step in demonstrating the effectiveness of liquid argon TPCs for sensitive discrimination of backgrounds to neutrino interactions. If the experiment is sited in the MINOS surface building, it would be exposed to both the BNB to accomplish MicroBooNE. It would also be exposed to a very off-axis NuMI beam, providing useful study of low-energy neutrinos, although it may be desirable to have a LAr detector down in the NuMI tunnel to act as a NOvA near detector. Both detector sitings would produce useful neutrino scattering measurements relevant for oscillation physics, as well as scattering measurements of relevance for nuclear physics. Smaller scale LAr experiments like this can provide very useful experience toward potential long-baseline detectors.

The strange quark contribution to nucleon spin (Δs) can be extracted from neutral current elastic (NC-elastic) scattering in the Booster neutrino beam with higher precision and less model-dependence than in deep-inelastic scattering measurements. In addition to providing the strange quark piece of the proton spin puzzle, the Δs measurement has cosmological implications, as NC-elastic interactions dominate in core-collapse supernovae. At present, Δs results from polarized, inclusive, lepton deep-inelastic scattering and from semi-inclusive leptonic deep-inelastic scattering are not consistent with each other. Although given additional run time beyond that currently approved, the SciBooNE experiment could better measure the ratio of NC-elastic scattering to charged current (CC) scattering events, a fully sensitive experiment might require detector upgrades to SciBooNE. Required sensitivity is currently being studied.

Neutrino-nucleus cross-sections in the low energy (tens of MeV) regime for a number of nuclear targets pertinent to the process of supernova core collapse can be studied using a neutrino beam generated from stopped pions produced by very intense proton beams of 1-2 GeV, and an experiment similar to NuSNS at the Spellation Neutron Source (SNS). In addition, coherent elastic neutrino-nuclear scattering could possibly be measured, providing a precision test of the Standard Model not possible at the SNS because of neutron backgrounds.

Neutrino Science Experiments with 800 GeV Protons

Exciting experiments using high energy neutrinos produced in a TeVatron fixed target neutrino beam line could be performed if sufficient 120 GeV protons from the Main Injector are available to feed both the long-baseline neutrino program and the TeVatron. For example, a precision measurement of the weak mixing angle θ_W using muon neutrino scattering on electrons performed with a high energy neutrino beam could probe Beyond the Standard Model (BSM) physics in a way complementary to other electroweak measurements. Tension that presently exists in global electroweak fits perhaps hints at BSM effects. Only measurements of the invisible width of the Z in electron-positron collisions probe the Standard Model in the same way. Such a measurement of θ_W could be performed by an experiment dubbed NuSOnG that would utilize a new spectrometer in a pure muon neutrino or anti-neutrino beam generated by 800 GeV protons from the TeVatron with a sign-selected quadrupole train (SSQT). A measurement of $\sin^2(\theta_W)$ in neutrino-electron scattering to 0.7% could be produced with 2×10^{20} POT. Such an experiment could not be performed by any other neutrino beam at Fermilab, CERN, or J-PARC.

Upgrade to the Fermilab Proton Facility

During the era of NOvA operations, neutrino experiments in Booster or TeVatron neutrino lines cannot be supported without compromising NOvA physics, unless upgrades are made to the Fermilab proton accelerator complex. The sNuMI upgrade, which would increase the Main Injector beam power by approximately 50% to 1.1 MW, would increase the sensitivity and physics reach of the NOvA program. It would also increase the competitiveness of NOvA with its contemporary neutrino oscillation experiments. The sNuMI upgrade, however, would not provide adequate 8 GeV beam power available for experiments such as microBooNE or SciBooNE with upgrades. A precision electroweak neutrino experiment, such as NuSOnG, would require about 5% of the sNuMI 120 GeV beam power. Project X, on the other hand, would provide ample proton beam power to provide both a greater than three-fold increase in 120 GeV beam power for NOvA and future long-baseline experiments and more than ample 8 GeV beam power for neutrino experiments. The 120 GeV beam power available with Project X would also allow operation of a TeVatron fixed-target neutrino line without noticeable impact on the long-baseline neutrino program. Thus, Project X would enable a program of neutrino experiments that would not otherwise be feasible, while greatly enhancing the physics reach of long-baseline neutrino oscillation experiments.

Appendix D. Precision Physics at the Proton Facility

This section lists experiments with muon and kaon beams that could be carried out at the proton facility.

Precision Physics Experiments with Muon Beams

A muon to electron conversion experiment could be based on the detailed technical design of the MECO experiment that was planned to be run at the BNL AGS operating at 8 GeV. With low cost modifications to the current accelerator complex, this experiment would detect LFV if $R_{\mu e}$ $(\Gamma(\mu^- N \rightarrow e^- N)/\Gamma(\mu^- N \rightarrow \nu N'))$ is as small as 2×10^{-17}. It would collect data for 2-3 years with little or no impact on the beam available for the neutrino program, based on current plans to upgrade the 120 GeV beam to ~700 kW. The Fermilab beam implementation would be superior to that planned for BNL due to better duty factor (>90% vs. ~50%), superior micro time structure, and more running per year.

The MECO design has been reviewed for cost and technical feasibility in detail, and a new experiment based on MECO could be developed into a reviewable project at Fermilab with about one year of effort. Physics results at sensitivity below 10^{-16} would follow 4-5 years of construction and 2-3 years of running. Upgrades to use a more intense beam following the SNuMI or Project-X construction would be studied and then implemented following the first physics running period.

Precision Physics Experiments with Kaon Beams

The "KTeV-II" experiment described below is designed to make a precision measurement of the $K^+ \rightarrow \pi^+ \nu\nu$ branching fraction that matches the small theoretical uncertainty. In parallel with $K^+ \rightarrow \pi^+ \nu\nu$ running, the KTeV-II experiment can probe many other decay channels including precision measurement of $K^+ \rightarrow e^+ \nu$ and $K^+ \rightarrow \pi\mu e$ searches which are both uniquely incisive probes of BSM physics. The "KOPIO" experiment described below is designed to discover and measure the ultra-rare $K^0 \rightarrow \pi^0 \nu\nu$ decay process which is very sensitive to CP-violating BSM amplitudes. Several BSM models can be discovered or excluded on the road to the Standard Model expected $K^0 \rightarrow \pi^0 \nu\nu$ branching fraction of 3×10^{-11}. Upon acquiring the Standard Model sensitivity the experiment then becomes sensitive to very high mass scale (>1000 TeV/c^2) and extra-dimensional models through precision measurement of the $K^0 \rightarrow \pi^0 \nu\nu$ branching fraction.

The KTeV-II experiment is based on the conceptual design of the CKM experiment (Charged Kaons at the Main injector). Driving the experiment in the NuMI or SNuMI era with the high duty-factor Tevatron stretcher simultaneously reduces detector rates by x3 and the proton tax on the Main Injector neutrino program from 30% to 5%. The lower detector rates reduce the technical risk of the experiment and supports scaling of the CKM design to much higher sensitivity in the Project-X era. The high energy separated kaon beam based on ILC crab cavity technology drives this next step in ultra-rare K^+ sensitivity with samples of 100-200 $K^+ \rightarrow \pi^+ \nu\nu$ decays per year within reach. Project-X can further increase the rare-decay sensitivities by x3 while maintaining a small 5% tax on the Main Injector neutrino program. The CKM conceptual design has been technically reviewed in detail, and could be developed into a reviewable project with one year of effort. Several years (3-4) of funding and construction would then be necessary to start detector operations 5 years following a decision to proceed with this opportunity.

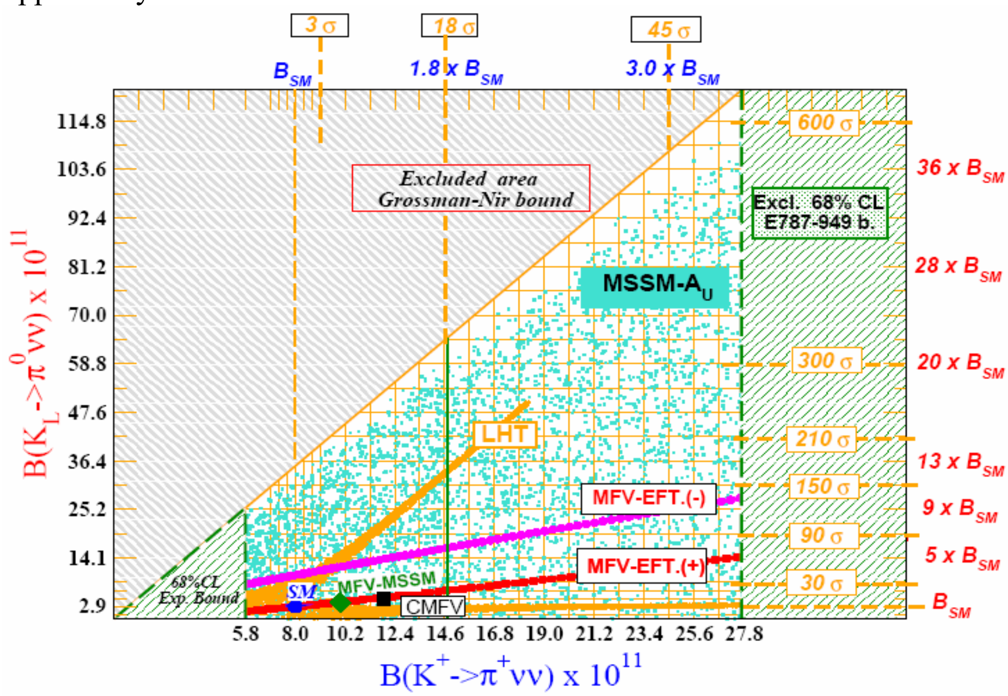

Illustration of the $K \rightarrow \pi\nu\nu$ sensitivity space for BSM physics compiled by F. Mescia for the CKM-2006 Workshop. The reach above the Standard Model in units of current (2007) theoretical certainty of the Standard Model prediction is indicated in orange, and is a space of about (50σ x 600σ) for (charged x neutral) modes. The current measurement of $K^+ \rightarrow \pi^+ \nu\nu$ based on 3 events by the BNL E787-949 experiment is x1.8 the Standard Model prediction. Several BSM models are indicated: Minimal SUSY (MSSM), "Little Higgs Theories" (LHT), and "Minimal Flavor Violation" (MFV).

The experiment was originally designed and optimized for the BNL AGS 24 GeV proton source. The KOPIO proponents have estimated the K^0 flux at the Fermilab Booster energy of 8 GeV and have found the flux to be comparable to the BNL AGS. The limited proton intensity of the AGS drove the KOPIO design to an unusually large solid-angle kaon beam in order to collect sufficient kaon decays to measure the $K^0 \rightarrow \pi^0 \nu\nu$ process. This large beam complicated the detector design and contributed technical risk to the experiment. The very large proton intensity of Project-X (x12 Booster intensity) motivates a re-optimization based on a much smaller solid angle beam which could deliver sufficient kaon decays. This smaller beam could significantly simplify the experiment and reduce technical risk. An experiment optimized for Project-X intensities could still have sufficient sensitivity to discover the $K^0 \rightarrow \pi^0 \nu\nu$ process in early running during the NuMI (no Nova proton tax) or SNuMI (10% Nova proton tax) era using the Fermilab Booster as a proton driver. The lower intensities of the Booster driving a smaller kaon beam would provide a natural timeline to develop and commission this challenging experiment. The KOPIO conceptual design has been reviewed in detail, and could be developed into a reviewable project with one year of effort. Several years (3-4) of funding and construction would then be necessary to start detector operations 5 years following a decision to proceed with this opportunity.

Appendix E. Facilities Considered

The Steering Group considered about twelve facilities. The table below lists the facilities that were not described in Section 4.

Facility	Description	Performance Parameters	Physics Program	ILC Synergy
Proton Facilities				
LHC Luminosity Upgrade	Luminosity Upgrade based on high performance IR quadruoples based on Nb_3Sn technology.	$L>1\times10^{35}$ $cm^{-2}sec^{-1}$	High energy frontier	No
Proton Complex Upgrade	New 8 GeV Booster fed by a new 1 GeV linac	2.3 MW beam power at 120 GeV (23×10^{20} protons/year) 8 GeV slow spill available by diverting protons from the 120 GeV program	Neutrino science and Precision Physics	No
Antiproton Facility	Continued operations of the Antiproton Source	2×10^{11} protons/hour at 8 GeV. Operated in storage mode. Incompatible with SNuMI. Minor hit on proton availability from Project X.	Precision physics	No
High Energy, High Power ν Beam	480 GeV dual aperture accelerator constructed in the Tevatron tunnel. Based on superferric magnet.	~5 MW beam power at 480 GeV (25×10^{20} protons/year)	Neutrino Science	No
Electron Facilities				
6 GeV ILC Linac	ILC 1% systems test in ILC like tunnel	ILC beam parameters 9ma x 1ms x 5Hz	NA	Yes
Giga-Z	90 GeV linear collider based on ILC technology	10^9 Z's $L>1\times10^{33}$ $cm^{-2}sec^{-1}$	Precision Physics	Yes
Super B Factory (*)	Asymmetric (4 GeV × 7 GeV) e+e- collider in the Tevatron tunnel	$L>1\times10^{36}$ $cm^{-2}sec^{-1}$	Precision Physics	No, unless converted ILC Damping Ring
ILC Damping Ring	5 GeV ILC damping ring in the Tevatron tunnel.	ILC Damping Ring Parameters	NA, unless converted to use as B factory	Yes

* B physics with Super B Factory A second generation B factory with luminosity above $10^{36}/cm^2/s$ providing data samples of 50-100 ab^{-1} can explore a wide range of physics

beyond the Standard Model. In many scenarios, the physics reach extends beyond the TeV scale and the pattern of deviation from Standard Model predictions can help distinguish between models. The possibility of constructing a super-B factory at Fermilab should be re-examined sometime around 2012 in light of LHC discoveries, progress on ILC development, and worldwide plans for super-B factories elsewhere.